

Generation Reliability Evaluation in Power Markets Using Monte Carlo Simulation and Neural Networks

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Abstract-- Deregulation policy has caused some changes in the concepts of power systems reliability assessment and enhancement. In this paper, generation reliability of Perfect Competition, Oligopoly and Monopoly power pool markets are evaluated using Neural Networks. Also, due to the stochastic behavior of power market and generators' forced outages, Monte Carlo Simulation is used for reliability evaluation. The proposed method is assessed on IEEE-Reliability Test System with satisfactory results. In the case studies, generation reliability indices are evaluated with different reserve margins and various load levels.

Index Terms-- Power market – Neural Networks - Power generation reliability - Monte Carlo methods.

I. INTRODUCTION

The power systems main emphasis is to provide a reliable and economic supply of electrical energy to the customers [1]. A real power system is complex, highly integrated and almost very large. It can be divided into appropriate subsystems in order to be analyzed separately [2]. This research deals with generation reliability assessment in power pool markets, and transmission and distribution systems are considered reliable and adequate as shown in Fig. 1.

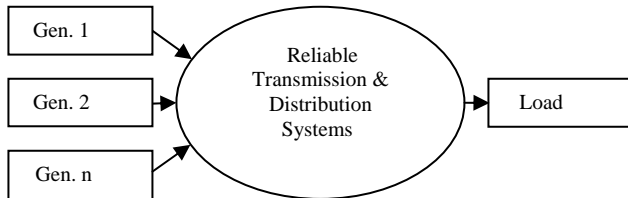


Fig.1. Power pool market schematic for HLI reliability assessment

Most of the methods used for generation reliability evaluation are based on the “loss of load or energy” approach. One of the suitable indices that describes generation reliability level is “Loss of Load Expectation” (*LOLE*), that is the time in which load is more than the available generation capacity.

Generally, the reliability indices of a system can be evaluated using one of the following two basic approaches [3]:

- Analytical techniques
- Stochastic simulation

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Simulation techniques estimate the reliability indices by simulating the actual process and random behavior of the system. Since power markets and generators' forced outages have stochastic behavior, Monte Carlo Simulation (MCS), as one of the most powerful methods for statistical analysis of stochastic problems, is used for reliability assessment in this research.

Generation reliability depends absolutely on the generating units specifications. The main function in traditional structure for Unit Commitment (UC) of the generators is to minimize generation costs. Since the beginning of the 21st century, many countries have been trying to deregulate their power systems and create power markets [4-8]. In the power markets, the main function of players is their own profit maximization, which severely depends on the type of the market. As a result, generation reliability assessment depends on market type and its characteristics.

Generally, economists divide the markets in four groups [9]:

- Perfect competition market
- Monopoly market
- Oligopoly market
- Monopolistic competition market

In Monopolistic competition market, the quality of goods which are produced by various companies, should be different each other. Since in this paper, we consider the quality of generated power of power plants as the same, therefore, Monopolistic competition market is ignored in this research.

Independent power producers' impact on reliability and associated costs of existing power systems under deregulation environment has been presented, where “Expected Unserved Power” (*EUP*) is used as reliability index and economic dispatch problem is solved under some reliability and system constraints [10].

Reference [11] has used “Effective Load Duration Curve” (*ELDC*) for evaluation of “Loss of Load Expectation” (*LOLE*) and “Expected Energy Not Served” (*EENS*) as reliability indices.

Reference [12] has presented some reliability models for different players in a power system, where generation system is represented by an equivalent multi-state generation provider (*EMGP*). The reliability parameters of each *EMGP* are shown by an available capacity probability table (*ACPT*), which is determined using conventional techniques. Then, the equivalent reliability parameters for each state (including state probability, frequency of encountering the state and the equivalent available generation capacity) are determined.

Generation operational cost minimization problem under system constrains and load uncertainty has been presented for

evaluation of “Expected Unserved Power” (*EUP*) as reliability index [13].

This paper considers HLI reliability evaluation in power pool markets using MCS and Neural Networks (N.N.). Also, sensitivity of reliability index to different parameters will be evaluated. In section-II fundamental of power pool markets will be discussed. In section-III, the algorithm of generation reliability assessment in power markets will be proposed, and finally, in section-IV the case study results will be presented and discussed.

II. POWER POOL MARKETS FUNDAMENTALS

Market demand curve has negative gradient, and the amount of demand decrease is explained by “price elasticity of demand”. This index is small for short terms, and big for long terms; because in longer terms, customers can better adjust their load relative to price [14]. Demand function, generally, is described as $P=a-b.Q$. Therefore, price elasticity of demand is explained as:

$$E_d = \left| \frac{dQ}{dP} \right| = \frac{1}{b} \quad (1)$$

Let’s suppose forecasted load by dispatching center is an independent power from price that equals to Q_n . Therefore, demand function can be obtained as:

$$P = a - b.Q = b.Q_n - b.Q = \frac{Q_n}{E_d} - \frac{Q}{E_d} \quad (2)$$

Also, total revenue is obtained as:

$$TR = P.Q = a.Q - b.Q^2 \quad (3)$$

Typically, price elasticity in power markets, is 0.1-0.2 for 2-3 future years and 0.3-0.7 for 10-20 future years as shown in Fig.2 [14].

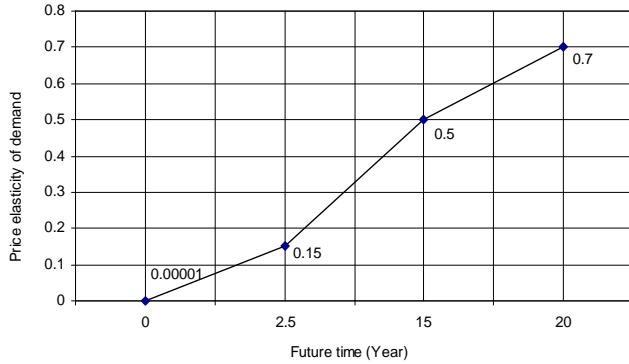


Fig.2. Price elasticity of demand for various times

Offer curve of a company, which participates in a market without any market power is part of the marginal cost curve that is more than minimum average variable cost [9]. Also, total offer curve of all companies is obtained from horizontal sum of each company’s offer curve. This curve is a merit order function. In economics, if sale price in a market becomes less than minimum average variable cost, the company will stop production; because the company will not be able to cover not only the fix cost but even the variable cost [9]. Due to the changing efficiency and heat rate of power

plants, marginal cost is less than average variable cost. Therefore, in power plants, average variable cost replaces marginal cost in economic studies [15].

In a perfect competition market, equilibrium amount is obtained from intersection of total offer curve and demand curve [9].

In a monopoly market, the monopolist considers the production level, which maximizes his profit. It is proved that the monopolist considers the level of production in which marginal cost of each firm (and total marginal cost of all firms) equals to the marginal revenue of the monopolist [9]:

$$MC_1 = MC_2 = \dots = MC = MR \quad (4)$$

Where:

$$MR = \frac{d(TR)}{d(Q)} = a - 2b.Q = \frac{Q_n}{E_d} - \frac{2.Q}{E_d} \quad (5)$$

In power markets, Hirschman-Herfindahl Index (*HHI*), which is obtained from (6), is used for market concentration measurement [16]:

$$HHI = \sum_M q_i^2 \quad (6)$$

In an oligopoly power market, each company can mark up the price based on its plants specifications and the price elasticity of demand. If concentration of a market becomes less, each company’s share in the market will be decreased. Therefore, “market power” becomes less, too. Market power is the ability of a company to mark up the price in comparison with its marginal cost [17]. Market power for company n in an oligopoly power market is obtained using Lerner index as shown in (7) [17]:

$$L_n = \frac{P(Q) - MC(q_n)}{P(Q)} \quad (7)$$

By differentiation from revenue function of company n in Cournot-Nash model of an oligopoly power market, (8) is obtained [17]:

$$L_n = \frac{P(Q) - MC(q_n)}{P(Q)} = \frac{s_n}{E_d} \quad (8)$$

Where:

$$s_n = \frac{q_n}{Q}, \quad Q = q_1 + q_2 + \dots + q_M$$

Therefore, in an oligopoly power market, the most profitable offer price for company n with generated power q_n is:

$$P_n = \left(\frac{E_d}{E_d - s_n} \right) \times MC(q_n) \quad (9)$$

Formulas (8), (9) show that if the market share of a company increases, the company can mark up the price, more. Also, if price elasticity decreases, companies can mark up the market price, more.

Generation reliability of a power system depends on many parameters. One of these parameters which has an important role, is reserve margin that is defined as (10) [18].

$$RM\% = \frac{Installed\ Capacity - Peak\ Demand}{Peak\ Demand} \times 100 \quad (10)$$

III. PROPOSED METHODS FOR GENERATION RELIABILITY EVALUATION IN POWER MARKETS

The algorithm of generation reliability assessment in power pool markets using MCS is as follows (Fig.3):

- 1- Calculate total offer curve of power plants for each power market.
- 2- Select a day and its load (Q_n) randomly in MCS, and calculate demand exponent curve for each market (demand curve for perfect competition and oligopoly power markets, and marginal revenue curve for monopoly power market).
- 3- The plants which are selected for generation in the selected day are determined by intersection of power plants' total offer curve and demand exponent curve considering reserve margin.
- 4- For each selected power plant in the previous step, a random number between [0-1] is generated. If the generated number is more than the power plant's Forced Outage Rate (FOR), the power plant is considered as available in the mentioned iteration; otherwise it encounters forced outage and thus cannot generate power. This process is performed for all power plants using an independent random number generated for each plant. Finally, sum of the available power plants' generation capacities is calculated. If the sum becomes less than the intersection of power plants' total offer curve and demand exponent curve, we will have interruption in the iteration, and therefore, $LOLE$ will increase one unit; otherwise, we will go to the next iteration. The algorithm of available generated power and $LOLE$ calculations for each iteration in MCS is shown in Fig.4.
- 5- Steps 2-4 are repeated in MCS for final $LOLE$ calculation.

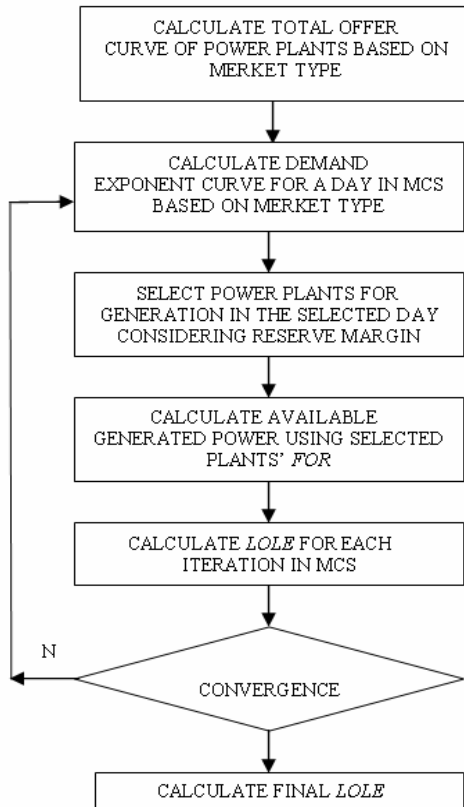


Fig.3. Flowchart of generation reliability assessment in power markets using MCS

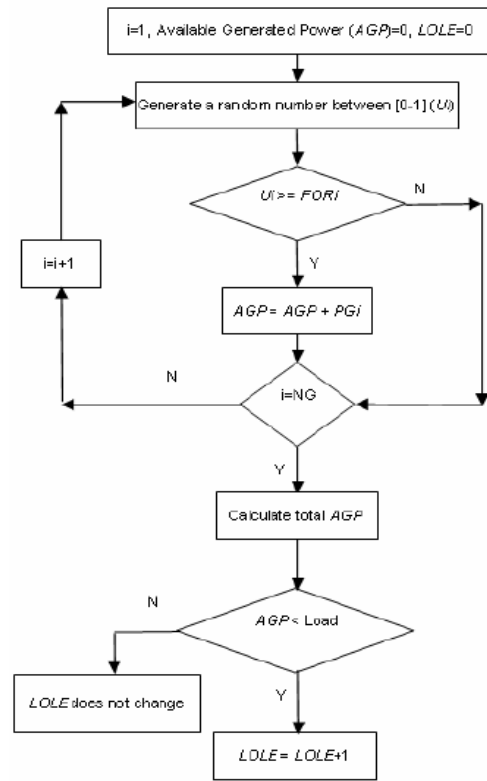


Fig.4. The algorithm of available generated power and $LOLE$ calculations for each iteration using MCS

Now, to create a unique structure which covers both outcomes, a four layers Perceptron neural network (N.N.) is used for reliability evaluation. The number of the neurons in each layer is 15, 12, 8 and 1, respectively as shown in Fig.5. All the neurons in first, third and last layers have POSLIN transfer function, and the second layer has TANSIG transfer function. Inputs of the neural network include:

- MT : Market type ("1" for perfect competition, "2" for monopoly and "3" for oligopoly power markets)
- Y : Simulated future year
- RM : Reserve margin

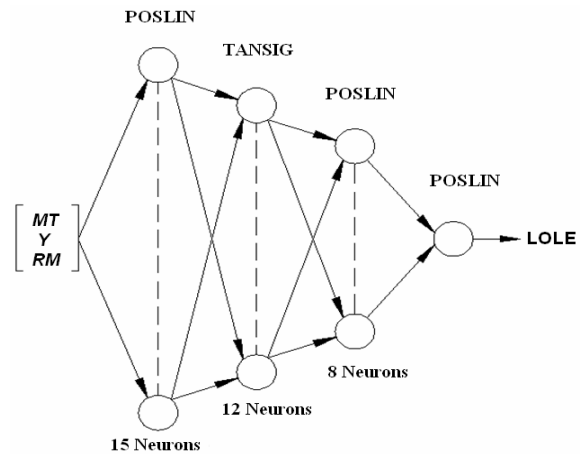


Fig.5. Proposed Neural Network for generation reliability evaluation in power markets

Also, *LOLE* is neural network's output.

Parts of the MCS results, obtained from the mentioned algorithms, are used for neural network training.

IV. NUMERICAL STUDIES

IEEE-Reliability Test System (IEEE-RTS) is used for case studies. The required data for IEEE-RTS can be found in [19]. The following assumptions are used in various case studies:

- 1- All case studies are simulated for the second half of the year, based on the daily peak load of the mentioned test system.
- 2- All simulations are done with 5000 iterations in MCS.
- 3- Each case study is simulated for two different times (second and fifth future years), and two reserve margins (0%, 9%).
- 4- Annual growth rates of power plants' generation capacity and consumed load are considered 3.4% and 3.34%, respectively.
- 5- Annual growth rates of oil and coal costs are considered 4% and 1%, respectively. Nuclear fuel cost (including uranium, enrichment and fabrication) is considered as a fixed rate. Also, annual growth rate of variable O&M cost is considered 1%.
- 6- Neural network is trained with TRAINLM method in MATLAB 7.0 software with 150 epochs. In this research, the neural network reached 0.1 Mean Square Error (MSE) after training.

In first study, market is perfect competition and each power plant belongs to an independent company ($MT="1"$ in N.N.). *LOLE* values are obtained for different times and reserve margins using MCS algorithm and proposed neural network as shown in Fig.6 and Fig.7, respectively.

In second study, all power plants belong to one monopolist, and the market is fully concentrated and monopoly ($MT="2"$ in N.N.). *LOLE* values are obtained for different times and reserve margins using MCS algorithm and proposed neural network as shown in Fig.8 and Fig.9, respectively.

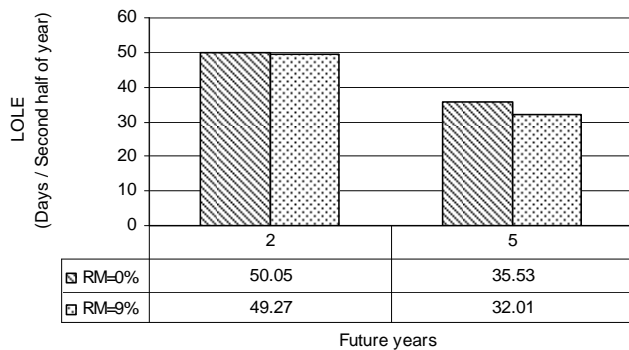


Fig.6. *LOLE* values for first study using MCS

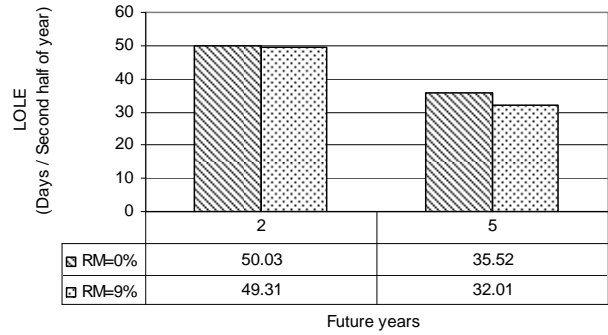


Fig.7. *LOLE* values for first study using Neural Network

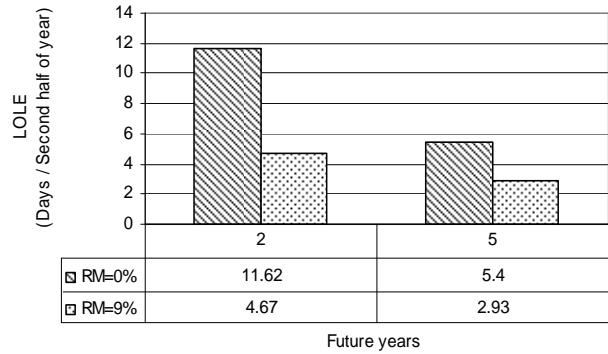


Fig.8. *LOLE* values for second study using MCS

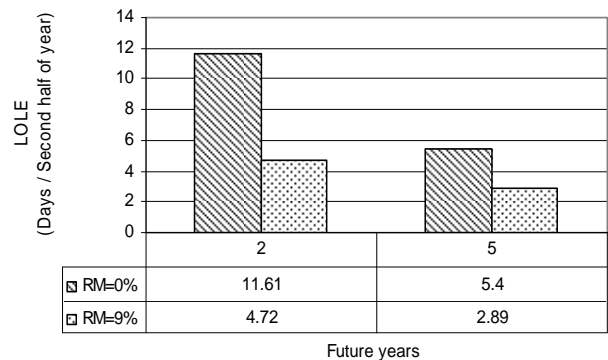


Fig.9. *LOLE* values for second study using Neural Network

In third study, market is oligopoly type ($MT="3"$ in N.N.), and each power plant belongs to an independent company. Therefore, *LOLE* values are obtained for different times and reserve margins using MCS algorithm and proposed neural network as shown in Fig.10 and Fig.11, respectively.

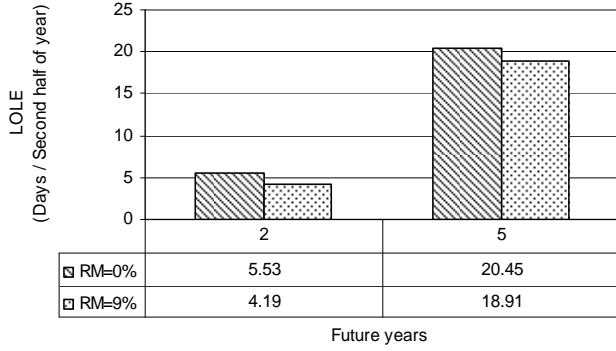


Fig.10. *LOLE* values for third study using MCS

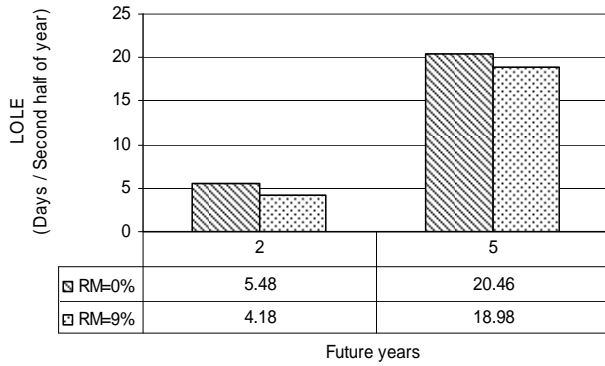


Fig.11. *LOLE* values for third study using Neural Network

As it is shown in all case studies, *LOLE* values in the neural network method are very similar to MCS values. Evidently, the neural network's specifications depend on the power system's characteristics, and the proposed neural network is valid for the mentioned power system. Therefore, neural network's specifications may be changed in another power system based on the power system parameters.

In all case studies, if reserve margin increases, *LOLE* will decrease and reliability will improve.

As mentioned before, in longer terms, customers can better adjust their load relative to the price. Therefore, price elasticity increases in longer terms, and according to (2) and (5), demand exponent curve reaches less gradient. As a result, intersection of the power plants' total offer curve and demand exponent curve will occur at less demand. This matter leads to operate from fewer power plants. Therefore, in each case study, if time increases, *LOLE* will decrease.

Since gradient of *MR* curve in monopoly market is twice gradient of demand curve in perfect competition market, intersection of plants' total offer curve and demand exponent curve in monopoly market occurs at less demand. This matter leads to operate from fewer power plants. Therefore, *LOLE*

has smaller values in monopoly power market in comparison with perfect competition power market.

In oligopoly power market, the main reason for *LOLE* increase in the future fifth year in comparison with the future second year, is change of plants' offer price, and therefore, change in plants' arrangement according to price. In third case study, in the future fifth year, *FOR* of the last plant which is selected for generation, is 0.12. This is while, in the future second year, *FOR* of the last plant which is selected for generation, is 0.02. Evidently, change in plants' offer price is due to the price elasticity change in different times.

It is to be noted that since available capacity of hydro plants in IEEE-RTS are different in the first and the second halves of the year, therefore, simulations were done for the second half of the year. Evidently, the proposed method can be utilized for every simulation time. Also, in this study, it was supposed that the annual additional generation capacity is uniformly distributed between all the present generators. If the generation planning scenarios in a power system are specified, then they can be used in the proposed method.

V. CONCLUSION

This research deals with generation reliability assessment in power pool markets using Monte Carlo simulation and Neural Networks. Due to the stochastic behavior of market and generators' *FOR*, MCS was used for the simulations. Also, for creation of a unique structure for reliability assessment, a neural network was used, which its outputs were very similar to MCS results. In this research, *LOLE* was used as reliability index and it was shown that if market becomes more concentrated, *LOLE* will decrease and reliability will improve. Also, if price elasticity of demand increases, *LOLE* will decrease.

VI. SYMBOL LIST

MC: Marginal cost (mills/kWh) (1 mills = 0.001 \$)

MR: Marginal revenue (mills/kWh)

TR: Total revenue (mills/h)

Q: Quantity of power (kW)

P: Electrical energy price (mills/kWh)

RM: Reserve margin (%)

E_i : Price elasticity of demand (kW²h/mills)

q_i : Share of i^{th} company from total installed capacity in the power pool market (%)

M: Number of independent companies in the market

Q_n : Forecasted load (kW)

LOLE: Loss of load expectation (Days / Second half of year)

FOR: Forced outage rate of power plants

a: Demand exponent curve cross of basis (mills/kWh)

b: Demand exponent curve gradient (mills/kW²h)

HHI: Hirschman - Herfindahl index

L_n : Lerner index of n^{th} company

MT: Market type

Y: Simulated future year

NG: Number of selected plants for generation in the market

AGP: Available generated power

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VIII. BIOGRAPHIES



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